

Hadronic Resonance Spectrum May Help in Resolution of Meson Nonet Enigmas

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Abstract

The identification of problematic meson states as the members of the quark model $q\bar{q}$ nonets by using a hadronic resonance spectrum is discussed. The results favor the currently adopted $q\bar{q}$ assignments for the axial-vector, tensor, and 1^3F_4 $J^{PC} = 4^{++}$ meson nonets, and suggest a new $q\bar{q}$ assignment for the

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scalar meson nonet which favors the interpretation of the $f_0(980)$ and $f_0(1710)$ mesons as non- $q\bar{q}$ objects. We also suggest that the $2\ ^3S_1\ \frac{1}{2}(1^-)$ state should be identified with the $K^*(1680)$ rather than $K^*(1410)$ meson.

Key words: hadronic resonance spectrum, quark model, hadron classification

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The existence of a gluon self-coupling in QCD suggests that, in addition to the conventional $q\bar{q}$ states, there may be non- $q\bar{q}$ mesons: bound states including gluons (gluonia and glueballs, and $q\bar{q}g$ hybrids) and multiquark states [1]. Since the theoretical guidance on the properties of unusual states is often contradictory, models that agree in the $q\bar{q}$ sector differ in their predictions about new states. Among the naively expected signatures for gluonium are

- i) no place in $q\bar{q}$ nonet,
- ii) flavor-singlet coupling,
- iii) enhanced production in gluon-rich channels such as $J/\Psi(1S)$ decay,
- iv) reduced $\gamma\gamma$ coupling,
- v) exotic quantum numbers not allowed for $q\bar{q}$ (in some cases).

Points iii) and iv) can be summarized by the Chanowitz S parameter [2]

$$S = \frac{\Gamma(J/\Psi(1S) \rightarrow \gamma X)}{\text{PS}(J/\Psi(1S) \rightarrow \gamma X)} \times \frac{\text{PS}(\gamma\gamma \rightarrow X)}{\Gamma(\gamma\gamma \rightarrow X)}, \quad (1)$$

where PS stands for phase space. S is expected to be larger for gluonium than for $q\bar{q}$ states. It should be pointed out, however, that mixing effects and other dynamical effects such as form-factors obscure these simple signatures. If the mixing is large, only counting the number of observed states remains a clear signal for non-exotic non- $q\bar{q}$ states. Exotic quantum number states ($0^{--}, 0^{+-}, 1^{-+}, 2^{+-}, \dots$) would be the best signatures for non- $q\bar{q}$ states. It should be also emphasized that no state has unambiguously been identified as gluonium, or as a multiquark state, or as a hybrid. In this letter we shall discuss meson states whose interpretation as the members of the conventional quark model $q\bar{q}$ nonets encounters difficulties, resulting in the corresponding enigmas [3]. We shall be mainly concerned with the scalar, axial-vector, and tensor meson nonets which have the following $q\bar{q}$ quark model assignments, according to the most recent Review on Particle Properties [4]:

- 1) $1\ ^3P_0$ scalar meson nonet, $J^{PC} = 0^{++}$, $a_0(980)$, $f_0(975)$, $f_0(1400)$, $K_0^*(1430)$
- 2) $1\ ^3P_1$ axial-vector meson nonet, $J^{PC} = 1^{++}$, $a_1(1260)$, $f_1(1285)$, $f_1(1510)$, K_{1A} ¹

¹The K_{1A} is a nearly 45° mixed state of the $K_1(1270)$ and $K_1(1400)$ [5].

3) 1^3P_2 tensor meson nonet, $J^{PC} = 2^{++}$, $a_2(1320)$, $f_2(1270)$, $f_2'(1525)$, $K_2^*(1430)$, and start with the discussion of the isoscalar states.

1. Scalar meson nonet.

There are four established isoscalars with $J^{PC} = 0^{++}$, the $f_0(975)$, $f_0(1400)$, $f_0(1590)$ and $f_0(1710)$, and two which need experimental confirmation, the $f_0(1240)$ and $f_0(1525)$. In the quark model, one expects two 1^3P_0 states and one 2^3P_0 ($u\bar{u} + d\bar{d}$)-like state below 1.8 GeV. Therefore, at least three of the six cannot find a place in the quark model. The $f_0(1400)$ and $f_0(975)$ are currently included as two 1^3P_0 states in the scalar meson nonet. There exists, however, an interpretation of the $f_0(975)$ as a $K\bar{K}$ molecule [6] since it [and the $a_0(980)$] lies just below the $K\bar{K}$ threshold which is 992 MeV [7]. If the $f_0(975)$ is not the 1^3P_0 $s\bar{s}$ state, the latter should be found near 1500 MeV with decay widths as expected from flavor symmetry. The weak signal at 1515 MeV claimed by the LASS group [8] does not have the expected large width [9]. In this case, the $f_0(1525)$ could be a candidate for the 1^3P_0 $s\bar{s}$ state [10]. This $f_0(1525)$ has been identified as $K\bar{K}$ S -wave intensity peaking at the mass of the $f'(1525)$ and having a comparable width [11, 12]. The $f_0(1240)$ is seen in phase shift analysis of the $K_s^0 K_s^0$ system [13]. At present, experimental data are not sufficient to draw firm conclusion on the nature of this state. The $f_0(1590)$ has been seen in $\pi^- p$ reactions at 38 GeV/c [14, 15]. It has a peculiar decay pattern for

$$\pi^0 \pi^0 : K\bar{K} : \eta\eta : \eta\eta' : 4\pi^0 = < 0.3 : < 0.6 : 1 : 2.7 : 0.8,$$

which could favor a gluonium interpretation [16]. Another possibility is that it is a large deuteron-like $(\omega\omega - \rho\rho)/\sqrt{2}$ bound state (“deuson”) [17]. With respect to the $f_0(1400)$, a large gluonium mixing is not excluded because the $\eta\eta/\pi\pi$ branching ratio is only half of the flavor-symmetry prediction [18]. The $f_0(1710)$ has been mainly seen in the “gluon-rich” $J/\Psi(1S)$ radiative decay, where it is copiously produced, and in central production by the WA76 experiment [19] at 300 GeV/c pp interactions. It has not been seen in hadronic production $K^- p \rightarrow K\bar{K}\Lambda$ [11] nor in $\gamma\gamma$ fusion. Its S parameter favors a large gluonium component. An attempt to justify the interpretation of the $f_0(1710)$ as a glueball has been done recently by Sexton *et al.* [20].

2. Axial-vector meson nonet.

The $q\bar{q}$ model predicts a nonet that includes two isoscalar 1^3P_1 states with masses below ~ 1.6 GeV. Three “good” 1^{++} objects are known, the $f_1(1285)$, $f_1(1420)$ and $f_1(1510)$, one more than expected. Thus, one of the three is a non- $q\bar{q}$ meson, and the $f_1(1420)$ is the best non- $q\bar{q}$ candidate [21]. Most likely, it is a multiquark state in the form of a $K\bar{K}\pi$ bound state (“molecule”) [22], or a $K\bar{K}^*$ deuteron-like state (“deuson”) [17].

3. Tensor meson nonet.

The two 1^3P_2 $q\bar{q}$ states are likely the well-known $f_2(1270)$ and $f_2'(1525)$ currently

adopted by the Particle Data Group [4], although the observation by Breakstone [23] of the $f_2(1270)$ production by gluon fusion could indicate that it has a glueball component. At least five more² $J^{PC} = 2^{++}$ states have to be considered: the $f_2(1520)$, $f_2(1810)$, $f_2(2010)$, $f_2(2300)$ and $f_2(2340)$. Of these, the $f_2(1810)$ is likely to be the 2^3P_2 , and the three f_2 's above 2 GeV could possibly be the $2^3P_2 s\bar{s}$, $1^3F_2 s\bar{s}$, and $3^3P_2 s\bar{s}$, but a gluonium interpretation of one of the three is not excluded. The remaining $f_2(1520)$ has been rediscovered in 1989 by the ASTERIX collaboration [25] as a 2^{++} resonance in $p\bar{p}$ P -wave annihilation at 1565 MeV in the $\pi^+\pi^-\pi^0$ final state. Its mass is better determined in the $3\pi^0$ mode by the Crystal Barrel collaboration [26] to be 1515 MeV, in agreement with that seen previously [27]. It has no place in a $q\bar{q}$ scheme mainly because all nearby $q\bar{q}$ states are already occupied. Dover [28] has suggested that it is a “quasinuclear” $N\bar{N}$ bound state, and Törnqvist [17] that it is a deuteron-like $(\omega\omega + \rho\rho)/\sqrt{2}$ “deuson” state.

Let us now briefly dwell upon another problematic member of the scalar meson nonet, the isovector-scalar $a_0(980)$. Its mass, (982 ± 2) MeV, is low, compared to its isovector partners, like the $a_1(1260)$, $a_2(1320)$ and $b_1(1235)$. Its apparent width (as measured in its $\eta\pi$ decay mode), (54 ± 10) MeV, is small, compared to its partners (which have 100 MeV and more). Moreover, neither the relative coupling of the $a_0(980)$ to $\eta\pi$ and $K\bar{K}$, nor its width to $\gamma\gamma$, are known well enough to draw firm conclusions on its nature ($q\bar{q}$, $2q2\bar{q}$ state, $K\bar{K}$ molecule, etc.) Another known $1^-(0^{++})$ state is the $a_0(1320)$. This state, identified as intensity peaking at the mass of the $a_2(1320)$ and having a comparable width [29], needs experimental confirmation.

A new candidate, the $a_0(1450)$, has been recently reported by the Crystal Barrel Collaboration at LEAR [30]. This $a_0(1450)$ is observed in the annihilations $p\bar{p} \rightarrow \eta\pi^0\pi^0$ at rest in liquid hydrogen. One finds that in this particular reaction, the dominant initial state is unique, i.e., 1S_0 , and in the final state one observes dominantly processes of the type $0^{-+} \rightarrow 0^{-+} + 0^{++}$, like $p\bar{p} \rightarrow \eta f_0(975)$, $p\bar{p} \rightarrow \pi a_0(980)$. *A priori*, one may suppose that the $a_0(980)$ is the ground state of the $q\bar{q}$ $I = 1$ $J^{PC} = 0^{++}$ meson, and the $a_0(1450)$ its radial excitation. One may as well suggest that the $a_0(980)$ is a non- $q\bar{q}$ object and the $a_0(1450)$ [or $a_0(1320)$] is the ground state of the $1^-(0^{++})$. In this way, an attractive choice for the $q\bar{q}$ scalar meson nonet could be the $a_0(1450)$, $K_0^*(1430)$, $f_0(1400)$ and $f_0(1525)$ or $f_0(1590)$, as suggested recently by Montanet [10]. This choice would leave out the $a_0(980)$ and $f_0(975)$ which could be then interpreted in terms of four-quark or $K\bar{K}$ molecule states, and one may then speculate, with some good reasons, that the $f_0(1710)$ is a glueball, or, at least, a state rich in glue, in favor of the arguments of Sexton *et al.* [20].

In this letter we suggest non-traditional approach to the problem of the identifi-

²We do not consider the $f_2(1430)$, $f_2(1640)$, $f_2(2150)$ and $f_2(2175)$ states which are included in the recent Meson Summary Table [24] but need experimental confirmation.

cation of the true $q\bar{q}$ states, viz., the use of a hadronic resonance spectrum. It is well known that the correct thermodynamic description of hot hadronic matter requires consideration of higher mass excited states, the resonances, whose contribution becomes essential at temperatures $\sim O(100)$ MeV [31, 32]. The method for taking into account these resonances was suggested by Belenky and Landau [33] as considering unstable particles on an equal footing with the stable ones in the thermodynamic quantities; e.g., the formulas for the pressure and energy density in a resonance gas read

$$p = \sum_i p_i = \sum_i g_i \frac{m_i^2 T^2}{2\pi^2} K_2\left(\frac{m_i}{T}\right), \quad (2)$$

$$\rho = \sum_i \rho_i, \quad \rho_i = T \frac{dp_i}{dT} - p_i, \quad (3)$$

where g_i are the corresponding degeneracies,

$$g_i = \begin{cases} (2J_i + 1)(2I_i + 1) & \text{for non-strange mesons} \\ 4(2J_i + 1) & \text{for strange (K) mesons} \\ 2(2J_i + 1)(2I_i + 1) \times 7/8 & \text{for baryons} \end{cases}$$

These expressions may be rewritten with the help of a *resonance spectrum*,

$$p = \int_{m_1}^{m_2} dm \tau(m) p(m), \quad p(m) \equiv \frac{m^2 T^2}{2\pi^2} K_2\left(\frac{m}{T}\right), \quad (4)$$

$$\rho = \int_{m_1}^{m_2} dm \tau(m) \rho(m), \quad \rho(m) \equiv T \frac{dp(m)}{dT} - p(m), \quad (5)$$

normalized as

$$\int_{m_1}^{m_2} dm \tau(m) = \sum_i g_i, \quad (6)$$

where m_1 and m_2 are the masses of the lightest and heaviest species, respectively, entering the formulas (2),(3).

In both the statistical bootstrap model [34, 35] and the dual resonance model [36], a resonance spectrum takes on the form

$$\tau(m) \sim m^a e^{m/T_0}, \quad (7)$$

where a and T_0 are constants. The treatment of hadronic resonance gas by means of the spectrum (7) leads to a singularity in the thermodynamic functions at $T = T_0$ [34, 35] and, in particular, to an infinite number of the effective degrees of freedom in the hadronic phase, thus hindering a transition to the quark-gluon phase. Moreover, as shown by Fowler and Weiner [37], an exponential mass spectrum of the form (7) is incompatible with the existence of the quark-gluon phase: in order that a phase transition from the hadron phase to the quark-gluon phase be possible, the hadronic spectrum cannot grow with m faster than a power.

In our previous work [38] we considered a model for a transition from a phase of strongly interacting hadron constituents, described by a manifestly covariant relativistic statistical mechanics which turned out to be a reliable framework in the description of realistic physical systems [39], to the hadron phase described by a resonance spectrum, Eqs. (4),(5). An example of such a transition may be a relativistic high temperature Bose-Einstein condensation studied by the authors in ref. [40], which corresponds, in the way suggested by Haber and Weldon [41], to spontaneous flavor symmetry breakdown, $SU(3)_F \rightarrow SU(2)_I \times U(1)_Y$, upon which hadronic multiplets are formed, with the masses obeying the Gell-Mann–Okubo formulas [42]

$$m = a + bY + c \left[\frac{Y^2}{4} - I(I+1) \right]; \quad (8)$$

here I and Y are the isospin and hypercharge, respectively, and a, b, c are independent of I and Y but, in general, depend on (p, q) , where (p, q) is any irreducible representation of $SU(3)$. Then the only assumption on the overall degeneracy being conserved during the transition leads to the unique form of a resonance spectrum in the hadron phase:

$$\rho(m) = Cm, \quad C = \text{const.} \quad (9)$$

Zhurov and Shuryak [43] have found the same result on a phenomenological ground. As shown in ref. [43], the spectrum (9), being used in the formulas (4),(5) (with the upper limit of integration being infinity), leads to the equation of state $p, \rho \sim T^6$, $p = \rho/5$, called by Shuryak the “realistic” equation of state for hot hadronic matter [31], which has some experimental support. Zhurov and Shuryak [43] have calculated the velocity of sound, $c_s^2 \equiv dp/d\rho = c_s^2(T)$, with p and ρ defined in Eqs. (2),(3), and found that $c_s^2(T)$ at first increases with T very quickly and then saturates at the value of $c_s^2 \simeq 1/3$ if only the pions are taken into account, and at $c_s^2 \simeq 1/5$ if resonances up to $M \sim 1.7$ GeV are included.

We have checked the coincidence of the results given by a linear spectrum (9) with those obtained directly from Eq. (2) for the actual hadronic species with the corresponding degeneracies, for all well-established hadronic multiplets, the mesons:

$$\begin{aligned} 1 \ ^3S_1 \ J^{PC} = 1^{--} \text{ nonet, } \rho(770), \omega(783), \phi(1020), K^*(892) \\ 1 \ ^3D_3 \ J^{PC} = 3^{--} \text{ nonet, } \rho_3(1690), \omega_3(1670), \phi_3(1850), K_3^*(1780), \end{aligned}$$

the baryons:

$$\begin{aligned} J^P = \frac{1}{2}^+ \text{ octet, } N(939), \Lambda(1116), \Sigma(1190), \Xi(1320) \\ J^P = \frac{3}{2}^+ \text{ decuplet, } \Delta(1232), \Sigma(1385), \Xi(1530), \Omega(1672) \\ J^P = \frac{3}{2}^- \text{ nonet, } N(1520), \Lambda(1690), \Sigma(1670), \Xi(1820), \Lambda(1520) \\ J^P = \frac{5}{2}^+ \text{ octet, } N(1680), \Lambda(1820), \Sigma(1915), \Xi(2030), \end{aligned}$$

and found it excellent [38]. Therefore, the fact established theoretically that a linear spectrum is the actual spectrum in the description of individual hadronic multiplets, finds its experimental confirmation as well.

Now we wish to apply the linear spectrum (9) to the problem of the identification of the $q\bar{q}$ nonets, as follows: we shall be looking for such a composition of a nonet for which the results given by both the formulas (2), and (4) with a linear spectrum, coincide (or, at least, are very close). We shall proceed as in a previous paper [38]: instead of a direct comparison of Eqs. (2) and (4), we shall compare the expressions p/p_{SB} for both cases, where $p_{SB} \equiv \sum_i g_i T^4/\pi^2$ (i.e., p_{SB} is the pressure in an ultrarelativistic gas with $g = \sum_i g_i$ degrees of freedom).

In order to illustrate how the suggested method works in practice, let us first consider another meson nonet not discussed above:

$$2\ ^3S_1\ J^{PC} = 1^{--},\ \rho(1450),\ \omega(1390),\ \phi(1680),\ K^*(1410).$$

As suggested by the recent Particle Data Group [5], in this currently adopted $q\bar{q}$ assignment, the $K^*(1410)$ could be replaced by the $K^*(1680)$ as the $2\ ^3S_1$ state (The $K^*(1680)$ is currently placed as a member of the $1\ ^3D_1\ J^{PC} = 1^{--}$ nonet). We have checked the both possibilities,

$$1)\ \rho(1450),\ \omega(1390),\ \phi(1680),\ K^*(1410),$$

$$2)\ \rho(1450),\ \omega(1390),\ \phi(1680),\ K^*(1680),$$

and compared the ratios p/p_{SB} in both cases. Our results are shown in Fig. 1,2. One sees that for the currently adopted assignment, the curves match very little; in contrast, for the assignment suggested by the Particle Data Group, the curves almost coincide. Therefore, the latter is favored from the viewpoint of a hadronic resonance spectrum.

Now we turn to the nonets discussed above. We have checked all possibilities for composing a nonet with the isoscalar states by choosing the latter among the states discussed above, and tried the three isovector states for the scalar meson nonet. The following summarizes the results of this work.

1. For the scalar meson nonet, we found that with one of the states, $f_0(975)$ or $f_0(1710)$ included in the nonet, the curves p/p_{SB} as calculated from both Eqs. (2), and (4) with a linear spectrum, do not match, or match very little, which means that the currently adopted nonet assignment (with the $f_0(975)$ included) does not agree well with our criterion of a linear spectrum being the actual spectrum of a multiplet. With the remaining scalar mesons (among those discussed above) included, the following are the combinations for which the curves coincide (Figs. 3–8):

with the $a_0(980)$,

$$1)\ a_0(980),\ f_0(1240),\ f_0(1400),\ K_0^*(1430),$$

$$2)\ a_0(980),\ f_0(1400),\ f_0(1525),\ K_0^*(1430),$$

$$3)\ a_0(980),\ f_0(1525),\ f_0(1590),\ K_0^*(1430);$$

with the $a_0(1320)$,

$$4)\ a_0(1320),\ f_0(1240),\ f_0(1525),\ K_0^*(1430);$$

with the $a_0(1450)$,

$$5)\ a_0(1450),\ f_0(1400),\ f_0(1525),\ K_0^*(1430).$$

The latter is the $q\bar{q}$ assignment suggested by Montanet [10].

2. For axial-vector and tensor meson nonets, in either case the best choice coincides with the composition currently adopted by the Particle Data Group, i.e.,

$$a_1(1260), f_1(1285), f_1(1510), K_{1A}$$

for the axial-vector nonet, and

$$a_2(1320), f_2(1270), f_2'(1525), K_2^*(1430)$$

for the tensor nonet.

3. We have also checked the currently adopted composition of another nonet,

$$1\ ^3F_4\ J^{PC} = 4^{++},\ a_4(2040),\ f_4(2050),\ f_4(2220),\ K_4^*(2045),$$

of which two states, $a_4(2040)$ and $f_4(2220)$, need experimental confirmation, and found that for this composition the curves match almost perfectly.

The main conclusion of this work is that a linear resonance spectrum suggests a new $q\bar{q}$ assignment for the scalar meson nonet which favors the interpretation of the $f_0(975)$ and $f_0(1710)$ mesons as non- $q\bar{q}$ objects. As we have seen, a linear resonance spectrum turns out to work very effectively towards resolution of meson nonet enigmas, for all meson nonets discussed in the letter except for the scalar meson nonet for which it is still impossible to make a unique prediction. For the scalar meson nonet, further exclusion of non- $q\bar{q}$ states should be made by using the standard methods, e.g., the Regge phenomenology. In this way, one may exclude the $a_0(980)$ as a state which does not fit as a $q\bar{q}$ state lying on a linear Regge trajectory (as well as $f_0(975)$ and $f_1(1420)$ [44]), thus leaving two possibilities for the nonet,

$$a_0(1320), f_0(1240), f_0(1525), K_0^*(1430),$$

$$a_0(1450), f_0(1400), f_0(1525), K_0^*(1430),$$

which may, in turn, be justified by the calculation of Horn and Schreiber [45] who calculated the mass of the lowest-lying 0^{++} scalar state by using the t -expansion method for Hamiltonian lattice QCD with two massless quarks, to be ~ 1.3 GeV, which is close to the mass of the lowest-lying scalar state for these assignments.

One can speculate even further. The leading Regge trajectory corresponding to the ρ meson resonances is described by the straight line

$$J = 0.58 + 0.84\ M^2 \tag{10}$$

to a high accuracy. Six resonance states, the $\rho(770)$, $a_2(1320)$, $\rho_3(1690)$, $a_4(2040)$, $\rho_5(2350)$, $a_6(2450)$, with isospin $I = 1$ and $J^{PC} = 1^{--}, 2^{++}, 3^{--}, 4^{++}, 5^{--}, 6^{++}$, respectively, belong to this trajectory as the $1\ ^3S_1$, $1\ ^3P_2$, $1\ ^3D_3$, $1\ ^3F_4$, ... states. In terms of the nonrelativistic quark model, these resonance states are interpreted as the states of the spin $q\bar{q}$ triplet with the maximal angular momentum $L = 0, 1, 2, 3, 4, 5$, respectively. The isovector states $1\ ^3P_0$, $1\ ^3D_1$, $1\ ^3F_2$, ... should belong to the parallel daughter Regge trajectory and correspond to the states with

$J^{PC} = 0^{++}, 1^{--}, 2^{++}, \dots$, and $L = 0, 1, 2, \dots$, respectively. Of these, the $\rho(1700)$ is well established as the 1^3D_1 $J^{PC} = 1^{--}$ state. Among the remaining two 1^3P_0 $J^{PC} = 0^{++}$ candidates, $a_0(1320)$ and $a_0(1450)$ [and $a_0(980)$], the only $a_0(1320)$ belongs to the trajectory on which the $\rho(1700)$ lies, which is parallel to the leading one (it can be easily seen by observing that the $a_2(1320)$ and $\rho_3(1690)$, which belong to the latter, have the masses very close to those of the $a_0(1320)$ and $\rho(1700)$, respectively).

Analogously, the leading trajectory for the ω resonances is described by the straight line which almost coincide with (10),

$$J = 0.59 + 0.84 M^2, \quad (11)$$

and includes the resonance states $1^3S_1, 1^3P_2, 1^3D_3, \dots$ with $I = 0$, the $\omega(783)$, $f_2(1270)$, $\omega_3(1670)$, $f_4(2050)$, $f_6(2510)$, having $J^{PC} = 1^{--}, 2^{++}, 3^{--}, 4^{++}, 6^{++}$ and $L = 0, 1, 2, 3, 5$ respectively. The isoscalar states $1^3P_0, 1^3D_1, 1^3F_2, \dots$, should belong to the daughter trajectory as those with $J^{PC} = 0^{++}, 1^{--}, 2^{++}, \dots$, and $L = 0, 1, 2, \dots$. Of these, the $\omega(1600)$ is well established as the 1^3D_1 $J^{PC} = 1^{--}$ state, and among the 1^3P_0 $J^{PC} = 0^{++}$ candidates, the only $f_0(1240)$ belongs to the same trajectory which is parallel to the leading one (it is easily seen by observing that the $f_2(1270)$ and $\omega_3(1670)$ belong to the latter).

Thus, the Regge phenomenology favors the only 1^3P_0 $J^{PC} = 0^{++}$ isovector $a_0(1320)$ and isoscalar $f_0(1240)$ states, leaving, therefore, the unique possibility for the scalar meson nonet assignment, from those already favored by a linear resonance spectrum,

$$a_0(1320), f_0(1240), f_0(1525), K_0^*(1430).$$

While the $K_0^*(1430)$ apparently belongs to the daughter trajectory, $K_0^*(1430), K^*(1680), K_2^*(1980)$, which is parallel to the leading one, $K^*(892), K_2^*(1430), K_3^*(1780), K_4^*(2045), K_5^*(2380)$, described by the straight line

$$J = 0.32 + 0.84 M^2, \quad (12)$$

nothing can be said about the $f_0(1525)$, since its nearby trajectory partner, the 1^3D_1 $J^{PC} = 1^{--}$ $s\bar{s}$ state, is not established at present. We, however, note that the 1^3F_2 $J^{PC} = 2^{++}$ $s\bar{s}$ state may well be the $f_2(2300)$ [or one of the $f_2(2340), f_2(2150), f_2(2175)$], as discussed above, which lies on a mutual trajectory with the $f_0(1525)$, parallel to the leading one, $\phi(1020), f_2'(1525), \phi_3(1850), f_4(2220)$, described by the straight line

$$J = 0.04 + 0.84 M^2. \quad (13)$$

Although our conclusions need experimental support, it is most probable that the true $q\bar{q}$ assignment for the scalar meson nonet is that for which there is a mass degeneracy of the scalar and tensor meson nonet states with equal isospin and quark content,

$$\begin{aligned} 1^3P_0 \ J^{PC} = 0^{++}, \quad & a_0(1320), f_0(1240), f_0(1525), K_0^*(1430), \\ 1^3P_2 \ J^{PC} = 2^{++}, \quad & a_2(1320), f_2(1270), f_2'(1525), K_2^*(1430). \end{aligned}$$

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FIGURE CAPTIONS

Fig. 1. Temperature dependence of the ratio p/p_{SB} as calculated from: I. Eq. (2), II. Eq. (4) with a linear spectrum, for the 2^3S_1 $J^{PC} = 1^{--}$ nonet with the assignment $\rho(1450)$, $\omega(1390)$, $\phi(1680)$, $K^*(1410)$.

Fig. 2. The same as Fig. 1 but with the $K^*(1410)$ replaced by $K^*(1680)$.

Fig. 3. The same as Fig. 1 but for the scalar meson nonet with the assignment $a_0(980)$, $f_0(1240)$, $f_0(1400)$, $K_0^*(1430)$.

Fig. 4. The same as Fig. 3 but with the $f_0(1240)$ replaced by $f_0(1525)$.

Fig. 5. The same as Fig. 3 but with the $f_0(1240)$, $f_0(1400)$ replaced by $f_0(1525)$, $f_0(1590)$.

Fig. 6. The same as Fig. 1 but for the scalar meson nonet with the assignment $a_0(1320)$, $f_0(1240)$, $f_0(1525)$, $K_0^*(1430)$.

Fig. 7. The same as Fig. 1 but for the scalar meson nonet with the assignment $a_0(1450)$, $f_0(1400)$, $f_0(1525)$, $K_0^*(1430)$.

Fig. 8. (An example of the curves which match little.) The same as Fig. 7 but with the $f_0(1525)$ replaced by $f_0(1590)$.















